

Table 3. Pond: Hydrological data during the period of maximum sexual development and activity from 5 August through 12 September 1975.

		Range	Mean
Temperature	C	27.6-31.5	28.9
Salinity	ppt	39.0-50.0	44.2
Oxygen	ppm	1.0-5.6	2.4
pH		8.0-8.6	8.3

DESIGN AND PRELIMINARY EVALUATION OF A CLOSED SYSTEM FOR SHRIMP CULTURE

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ABSTRACT

A closed system for intensive culture of penaeid shrimp was designed and tested. Details of construction of tanks and filters are presented along with a description of some equipment and procedures tested during the evolution of the system.

The system is evaluated in terms of its usefulness in rearing shrimp at high densities. Water chemistry parameters are presented to aid in evaluation of overall system performance.

It was demonstrated that the system has practical applications in rearing postlarval and juvenile penaeid shrimp at high densities.

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Methods for the culture of larval shrimp at high densities have been presented by Mock and Murphy (1971) and a comparison of these methods with Japanese techniques has been made by Mock and Neal (1974). Postlarval shrimp were reared at high densities in small closed systems by Mock, Neal, and Salser (1973). A series of experiments in closed raceways is discussed in this paper. The results of analyses of water are also presented.

METHODS AND MATERIALS

Raceways

The concrete hatchery raceway (5.2 x 2.4 x 0.8 m) had an area of 12.5 m². The center drain sump was 80 x 11 x 5 cm, and accommodated a 5-cm standpipe. Twenty-four 3.8-cm airlift pumps were distributed throughout the raceway in the pattern described in Figure 1 (A). The single center wall was constructed of corrugated fiberglass and suspended in the water column by a wooden frame so that a 5.0-cm space remained beneath the wall.

In cooperation with the University of Arizona Environmental Research Laboratory, two large concrete raceways were built, at the National Marine Fisheries Service Laboratory in Galveston. The large raceways were enclosed in an air inflated "aquacell" (Fig. 2). Structures of this type designed for use in aquaculture were described by Mahler, Groh, and Hodges (1974).

The two large concrete raceways were 24 x 3 x 0.9 m with a bottom area of 71.1 m² each, and were separated by a 0.85-m walkway. The corners were rounded, while the bottom sloped 0.5 degree to the center of the tank. In the center of each tank, a 0.3-m x 0.6-m rectangular drain tapered to a 10.2-cm PVC pipe, which accommodated a standpipe. The center drain pipe also sloped 0.5 degree toward the front of the raceway. There was an additional drain at either end, which accommodated a 5.0-cm standpipe. The drain pipes sloped gently toward their respective ends.

The 0.25-mm (10 mil) polyethylene cover attached to the outside concrete wall was inflated with a ½-HP blower. For air exchange, two 2-HP fans were activated either manually or by thermostats. Wind speed was monitored and, when necessary, internal pressure was increased in the bubble to prevent wind damage. Pressure control was implemented automatically through louvered windows. A natural gas-powered generator supplied electrical power during emergencies. Water and air temperatures were maintained automatically with a 700,000 BTU natural gas water heater. Hot water circulated through two air heaters and two submerged loops of CPVC 1.9-cm pipe in the center of each raceway.

To overcome the problem of clogging of airlift pipes we designed an airlift pump which was used 7 months without clogging. The new airlift was constructed of 3.8-cm schedule 40, PVC pipe (Fig. 3), and was composed of five parts:

- (1) A 90° elbow used at the top to deflect the water
- (2) A length of pipe
- (3) A short sanitary tee
- (4) An air stone with tubing
- (5) A fiberglass disc 1-mm thick

The fiberglass disc was cut to fit the center socket of the tee, a 0.6-cm hole was bored in the center of the disc, and it was glued into the center socket. All other pipe was fitted together without glue to facilitate cleaning and adjusting. Once the pieces were put together, an air line was inserted through the hole in the center socket of the sanitary tee, and an airstone was attached. The airstone was positioned inside the center socket rather than in the water flow.

The placement of airlift pumps in the raceways is shown in Figure 1. All three arrangements resulted in continuous circulation of water as well as through aeration and mixing.

Filtration of Suspended Particulate Wastes

To remove water containing particulate matter from the raceway, we designed two screening devices, a filter screen and a slotted pipe.

Filter screens (Fig. 3) were constructed of 0.3-cm or 0.6-cm plastic screening. The filter was constructed in a diamond shape with a flat top and bottom to avoid disruption of flow patterns and to reduce clogging. A 3.8-cm plastic pipe, with an adapter to fit the end drain, served as the support (Fig. 3). That portion of the pipe inside the screen was perforated with numerous 3.8-cm holes.

A single slotted pipe was designed to remove water and debris from the bottom of the tank. A 0.85-m length of 2.5-cm plastic pipe was slotted (Fig. 3) with the width of the slot depending upon the size of the shrimp in the system. The slotted pipe was then attached to a pipe as illustrated in Figure 3. The slotted pipe was held off the bottom 5 mm with a plastic bolt, which was inserted through the end of the slotted pipe. The bolt also prevented shrimp from entering the open end of the pipe.

The placement of slotted pipes (Fig. 1) in the raceways was determined based on Hjølstrom young stream building mechanics (Hjølstrom, 1939). A young stream erodes the bottom and outside banks and turns, with shoaling occurring on inside turns. With this in mind we controlled the velocity of the water (9.1 cm/sec), and were able to predict zones of sedimentation within the raceway. With the slotted pipe in position

(slot towards bottom of tank), it was observed that debris and sediment were picked up by the filter.

Separation of particulate matter from the water after it had been removed from the tank was accomplished using either a pressurized filter plate filter, a settling tank, an inclined plate separator or a liquid cyclone.

The Water Control Equipment Company ²/, Houston, Texas, made available to us two filter plate filters (Fig. 4). The porous filter plate located just above the bottom tank head was formed by injecting a 5.0-cm layer of silica sand with epoxy resin. The filter plate covered the inside diameter of the plastic-coated tank, thus water filtered straight down through the filter medium and through the filter plate, reducing channeling within the filter. All fittings and pipe used with the filter were plastic.

The most satisfactory filter medium for the plate filters was No. 3 Anthrafilt (anthracite which is first cleaned to reduce ash content and then screened and classified hydraulically). To aid in the back flushing of the filter, we alternately injected water and air. Two centrifugal pumps were used successfully with the pressurized filter; a 1/3-HP, CPVC pump (76 liters/min at 3.7 m) and a 1-HP, 304 stainless steel pump (152 liters/min at 3.7 m).

Our first settling container was a rectangular fiberglass tank (150 x 60 x 60 cm). Section A (Fig. 5) was made of four corrugated fiberglass panels which divided the tank into five channels. The panels rested on the bottom of the tank, but were bolted to the end walls. At one end of each panel, there was an opening 10 cm wide and 30 cm high to permit water to flow from channel to channel. At the end of the first channel, a 5.0-cm bulkhead fitting was attached to the bottom to serve as inlet port. Section B was separated from Section A by a wooden wall with a 5.0-cm hole to receive water from the last channel. At the opposite end of Section B a standpipe 5.0 cm in diameter and, 10.0 cm long served as the outlet port.

A settling tank was positioned so that the water level in the tank was the same as in the raceway. The water flowed through the standpipe to a 3.7-cm airlift pump back into the raceway. Flow rates were maintained at 32 liters/min with a working volume in the settling tank of 600 liters. By opening and closing appropriate valves, we were able to drain and flush this settling tank.

An inclined plate separator (designed furnished by the Pielkenroad Separator Co., Houston, Texas) was also tested. A cylindrical, flat-bottom polyethylene tank 105 cm in diameter, and 120 m tall was used to house eight closely spaced cones. The 55° cones were constructed of flat fiberglass and their edges were bolted together

(Fig. 6) with nylon bolts. These cones were then slipped over a 10-cm perforated header pipe. To hold the cones in position (5-cm intervals), they were bolted to each other. The perforations in the header pipe were four 2.5-cm holes (equally spaced) in the interval between each cone. Three 5-cm bulkhead fittings served as the inlet, outlet, and drain (Fig. 6).

Water entered the tank at the bottom through the header pipe, flowed up the header pipe, through the perforations and down between the cones. Particles settled on the cones while the fluid passed between the cones. Water left the separator through the outlet above the cones. As masses of particles built up on the cone walls, they slid to the edge of the cone and fell to the bottom of the tank. The outlet was placed below the surface of the water to prevent loss of floating sludge. When we removed sludge from the bottom, the unit was shut down. By opening and closing a series of valves and spraying with a hose, we were able to flush this unit. Unfortunately, we lost 750 liters of water each time we flushed this unit. A conical bottom tank would have facilitated flushing.

Flow from the outlet was pumped back to the raceway with a 3.8-cm airlift pump at a rate of 15.2 liters per minute. Since the water in the separator was at the same level as that in the raceway, whenever the separator volume was reduced, the raceway water was drawn up through the header. When the slotted pipe was used to screen the water, it restricted flow through the unit. We then placed a 3.0-cm airlift pump inside the header pipe, which pumped the water from the raceway to the separator thus improving flow rates. A modified protein skimmer was attached to the top of the header pipe and a line attached to the skimmer to drain the discharge.

Filtration of Dissolved Wastes

Three types of biological filters were tested during this experimentation. Our goal was to find a filter which was economical and which would permit easy recovery of the sloughed biological growth from the filter. The filters tested were an oyster shell trickling filter, a bio-disc filter, and a Pielkenroad trickling filter.

During testing of the oyster shell filter, water from the raceway was pumped through the pressurized filter, to remove particulate matter, then to the oyster shell trickling filter (Fig. 7). The filter was constructed in a 200-liter fiberglass tank (83 x 50 x 50 cm). A frame built of 1.3-cm plastic pipe supported the oyster shell media and allowed for a drainage zone under the media. The medium, 0.2 m³ of crushed oyster shell, was held in place with a plastic screen (0.3-cm mesh). The support frame was perforated with numerous 0.3-cm holes. With the frame in place, two plastic pipes which extended up through the filter media above the tank wall were attached to air and water supplies. By opening and closing valves we backwashed or injected air through the media. Water was introduced to the trickling filter at 38 liters/min through a header consisting of a 2.5-cm pipe, perforated with many 0.6-cm holes (Dow Chemical Co., 1971).

² Use of trade names in this publication does not imply endorsement of commercial products.

The rotating disc process is a secondary biological wastewater treatment system (Autotrol Corp., 1971). The basic unit consisted of a half cylinder tank, through the ends of which a horizontal shaft was mounted. A number of discs were closely spaced on the shaft (Fig. 8). As waste water flowed through the cylinder, the discs, which were half submerged, were rotated. Sessile aquatic microorganisms grew attached to the discs. This biological growth or slime layer acted as an aerobic biochemical agent, and removed the dissolved wastes from the water. As the slime layer thickened, those organisms nearer the surface of the disc died for lack of oxygen, and the entire layer sloughed off.

A modified rotating bio-disc was designed and built (Fig. 8). A 190-liter polyethylene tank was cut in half longitudinally, and the two halves connected to form a half cylinder tank. A wooden frame was then built to support this tank. Forty-eight fiberglass discs 50 cm in diameter and 1 mm thick were cut and drilled to accommodate support rods and the drive shaft. This unit had a surface area of 19.5 m². Four 0.8-cm wooden dowels (support rods) were passed through each disc and plastic spacers 2.5-cm long were placed between each disc on each support rod. A 1.6-cm stainless steel shaft supported by three sealed pillow blocks extended through the center of each disc. Power was supplied to the disc by a 1/20-HP gear motor with a 0.06-kg-cal torque. The drive shaft and gear motor were fitted with 4-step sheaves and a "0" type belt.

At either end of the tank a 2.5-cm bulkhead fitting was installed, 7.5 cm from the bottom, and a 57-liter tank with a float valve was connected to the disc tank. Water from the raceway was pumped through the pressurized filter to the 57-liter tank. The float valve regulated the volume of water flowing to the bio-disc tank where a standpipe on the opposite end directed the reconditioned water back to the raceway.

Although a bio-disc is usually operated in the dark, ours was exposed to natural light giving rise to a growth including a green micro-flora.

In cooperation with Mr. W. Melis of the Pielkenroad Separator Co., designs of a trickling filter were made available to us. We built our own filter utilizing the Pielkenroad filter medium and eliminating metal from the system. The Pielkenroad filter medium is a series of plastic sheets (filter packs) so arranged that a large surface area is available for biological growth within a small space. The plastic filter packs (117.5 x 58.7 x 97.5 cm) are thin indented sheets bonded together. Each pack has a surface area of 83.7 m².

Like the commercial Pielkenroad Filters, our filters were composed of three sections, a header box, a filter pack and a catch basin (Fig. 9). Water from the pressurized filter, containing little particulate matter, entered the header box at a rate of 38 liters/min. Along the sides of the header box, a series of 90° threaded 2.5-cm hose adaptor elbows directed an even flow of water to the diffuser, a corrugated fiberglass sheet directly below the header box. The water

flowed through numerous small slots and was distributed over a sheet of 0.6-cm mesh plastic netting, and across the top of the filter pack.

One filter pack was placed on top of the other, and they were supported by a wooden frame, and enclosed with sheets of corrugated fiberglass. Water entered the top of the filter and flowed down through the filter packs, while air entered the bottom of the pack and rose.

Aerobic organisms grew on the plastic sheets, utilizing oxygen in the air and dissolved substances in the waste water. As the layer of bacteria and algae grew thicker, pieces sloughed off. When this happened, the water being treated washed the sludge down through the filter.

Water and sludge from the filter pack were collected in the catch basin. Although a conical tank was recommended to facilitate sludge removal, we used a flat rectangular fiberglass tank (152.5 x 75 x 57.5 cm). A 1/4-HP plastic sump pump (152 liters/min) pumped the water back to the raceway. In order to keep the sump pump from siphoning the raceway water back to the catch basin, a small hole was drilled in the discharge water line, thus breaking the siphon.

The catch basin below the filter packs was vacuumed twice a week to remove the sludge build-up. To determine if the sludge was an attractive food for shrimp, 12 shrimp were placed in the catch basin. They immediately began consuming the sludge.

Feeding

Bottom feeding trays were made from plastic-coated wire racks (80 x 45 x 10 cm) lined with 0.3-cm mesh plastic netting. Four 1.2 cm x 5-cm plastic bolts served as legs and held the trays off the bottom.

Feeding troughs measuring 155 x 23 x 10 cm were constructed of 1.8-cm plastic pipe with 0.3-cm plastic netting and suspended in the water column by two handles. The troughs which were open at each end to allow for water flow were suspended 20 cm above the tank bottom.

Although the weights of the populations were difficult to estimate, feeding rates were roughly 50% to 60% of the population weight per day initially. The rate was reduced to about 5% to 8% per day for larger shrimp. Adjustments in feeding rates were made on the basis of shrimp growth, and the amount of excess feed in the tanks.

Chemical Analysis of Water

Water samples were collected at weekly intervals during the shrimp rearing experiments. The water samples were collected in 4-liter beakers immediately before (influent) and after (effluent) passing through the filters. The 4-liter samples were held 10 minutes for settling, then the upper 1,000 ml were used for the dissolved inorganic analyses. No filtration was used during the analytical procedures. The temperature of the sea water samples was measured in situ with a mercury thermometer.

Salinity, pH, and alkalinity determinations were made shortly following collection of water samples. The pH of the sea water samples was determined using a Corning Model 10-pH meter with glass electrodes. Salinity was measured with an American Optical refractometer. The Strickland and Parsons (1968) method was used for measuring total alkalinity.

All reaction and sample storage glassware was cleaned with chromic acid and rinsed with distilled water. When immediate analyses were not possible, the samples were stored for up to 7 days using the following procedure. Hard glass tubes, 25 x 200 mm, which had previously been stored full of distilled water, were emptied, rinsed in the sea water sample and then filled to about 70% capacity. Bakelite screw caps with polyethylene inserts were attached to the tubes, and these samples were stored in a freezer at -20°C . Before chemical analyses, the frozen samples were defrosted at room temperature, $23^{\circ}\text{C} \pm 3^{\circ}\text{C}$, with an electric fan.

Solorzano's (1969) simplified method for the determination of ammonia was used. For this test, glassware was rinsed with warm 10% HCl before use. The procedure described by Bendschnieder and Robinson (1952) was selected for the measurement of nitrate. The method described by Jenkins and Medsker (1964) was chosen for measurement of nitrate primarily because of its consideration of controlled heating and chloride masking. The Strickland and Parsons (1968) method was chosen to determine the concentration of inorganic phosphate phosphorous. All glassware was rinsed with the mixed reagents before use. The concentrations of ammonia, nitrite, nitrate, and inorganic phosphate phosphorous were determined colorimetrically with the aid of a Fischer Electrophotometer.

RESULTS

In the experiments described, postlarval shrimp were reared initially in a small hatchery raceway for efficient use of space and feed and then transferred to the large raceways in the aquacell. The sizes at which shrimp were transferred from the small to the larger raceways are noted on the appropriate figures below.

Rearing Experiment A

During the first experiment, circulation and turnover were maintained with 112 airlift pumps (pumping rate 199-120 liters/min/pump), which were suspended in each raceway (Fig. 1A). Flow was clockwise at 9.2 cm/sec. The plastic cover was clear.

On November 17, 1972, brown shrimp, *Penaeus aztecus*, were spawned and reared to the postlarval stage, utilizing techniques developed at the National Marine Fisheries Service Biological Laboratory, Galveston, Texas (Mock and Murphy, 1971). Twelve days later, 2,500 ($156/\text{m}^2$) postlarval shrimp were transferred to the hatchery raceway ($5.9 \times 2.5 \times 0.9 \text{ m}$). Water depth was maintained at 0.6 m, and tank volume was 12,800 liters. Due to tank leakage, 100 liters of sea water had to be added each day. The raceway was enclosed in a fiberglass

house. Growth of shrimp in this raceway is presented in Figure 10.

Initially, *Artemia* were fed at a level of 3/ml for 4 days following which the maintenance diet 5-5-70B (Meyers and Zein-Eldin, 1973) was ground finely and fed. The raceway was operated for 58 days without a filter. Fecal material which accumulated on the bottom of the tank was removed with a suction cleaner.

Beginning January 20, Tetra-Marine flake was introduced (ground to a small particle) hourly on the surface with an automatic feeder. Twenty days later we began feeding the diet 5-5-70B initially in flake form and later as an extruded pellet. The extruded diet was fed in two feeding trays which were lowered on each side of the raceway. Feed was introduced to each tray by dropping the food through a pipe, which guided the feed to the tray.

On April 25, 97% of the original population was harvested. The average length was 55.4 mm and the average weight 1.17 g. A great deal of debris was present on the bottom of the tank at the time of harvest.

Fresh seawater was pumped back into the raceway and 1,000 of the shrimp harvested were returned to the small hatchery raceway. A rectangular settling tank with a crushed oyster shell filter was added, and pumping rates were maintained through this filter at 120 liters/min. Old feed was used, but it accumulated on the bottom and began to foul. The bottom of the raceway was cleaned weekly, and a modified swimming pool filter charged with gravel was used for removal of particulate wastes.

Originally water was pumped from the system through a round filter screen (10 x 60 cm with 0.6-cm mesh). However, this screen had to be cleaned daily, so it was replaced with a slotted pipe held vertically in the water. The swimming pool filter would not backwash satisfactorily, and it was necessary to break it down manually every week and change the gravel. From July 12 through August 4, we had no feed. On September 10 the swimming pool filter was replaced with a pressurized plate filter charged with Anthrafilt, and operated at a flow rate of 40 liters/min.

On October 15, 395 shrimp (39.5%) were harvested (average length 120 mm and average weight 14.2 g) and transferred to a large raceway in the aquacell. Stocking rate in the larger aquacell was $5.6 \text{ shrimp}/\text{m}^2$. On November 1 we began using a trickling filter with a crushed oyster shell medium. Discharge from the trickling filter (40 liters/min) flowed back to the raceway.

A small pump (30 liters/min) was used to pump water through the slotted pipe to a 100-micron mesh Afco filter bag and back into the raceway. Bags were cleaned once a week. Within 2 weeks a growth of *Enteromorpha* appeared which often covered one-fifth of the water surface. Excess algae was removed, whenever flow was reduced. Filamentous algal growth was also heavy on the bottom.

Observations of water chemistry began on October 15, 1973 when the brown shrimp were introduced into the aquacell (Fig. 11).

Salinity ranged from 20 ppt to 30 ppt, and temperature fluctuated throughout the experiment between 16°C and 30°C. The concentration of ammonia ranged from 1.0 to 71.0 ug atoms NH₃-N/liter; nitrite 0.5-79.7 ug atoms NO₂-N/liter; nitrate from 7.1-214.0 ug atoms NO₃-N/liter; and inorganic phosphate phosphorus from 1.5 to 156.0 ug atoms PO₄-P/liter. The concentrations of these dissolved inorganic substances were lower than in succeeding experiments presumably due to the small population and lower feeding levels.

The system continued to function properly until this experiment was terminated in March 1974. Although only 79 shrimp (20%) were harvested from the aquacell, these shrimp were 484 days old and the following characteristics were noted:

Females (3)

Average total length - 104.3 mm
Average weight - 23.4 g
18 had some ovarian development
12 had been fertilized

Males (49)

Average total length - 133.4 mm
Average weight - 20.2 g
47 had spermatophores

Unfortunately, cold water temperature and insufficient feed hampered these experiments. However, a working closed system was beginning to emerge, and several preliminary observations were made. A non-clogging airlift pump was operating satisfactorily; water could be removed from the tank through a slotted pipe; and a pressurized filter with a suitable medium has been tested and adopted. Shrimp had been trained to feed from a submerged trough. The accumulation of debris on the bottom of the raceway was extensive, due to the attached filamentous algae on the bottom. Although the trickling filter was working, its filter media often clogged.

Rearing Experiment A

On August 30, 1973, 419,000 postlarval brown shrimp were placed in the small hatchery raceway (Fig. 12). Initial feeding was three *Artemia* nauplii/ml for 4 days after which the maintenance diet (5-5-70B) was ground to a powder and fed for 25 days. The feed was then shifted to a flake diet with the same ingredients. On October 5, 400,000 shrimp (95%) were harvested at an average length of 16.5 mm. No filters were used during this stage of the experiment.

On October 12, 1973, 7,344 of these shrimp (103/m²) were hand counted and placed in a large raceway within the aquacell. Initially, we fed with the flake every hour, then changed to the extruded particle which was placed in five submerged trays.

Twenty-two days after the experiment began the pressurized filter was activated and operated at a rate of 40 liters/min. Twenty-six days after the experiment was initiated we began operation of the bio-disc. The disc rotated at 13.5 rpm, and a flow rate through the

filter of 1 liter/min was maintained. When the feeding rate reached 400 g/day, the particulate load was building in the system. It was noted that the shrimp were very active and jumped a great deal. A sump pump was lowered directly into the raceway and water was pumped through a 100-micron filter bag for 6 hours per day at 160 liters/min. This procedure was continued for several days until we were able to install a modified swimming pool filter which was operated continuously at 40 liters/min. Slotted pipes were used on filter intakes at both ends of the raceway.

Water chemistry analysis began on October 12 when shrimp were introduced into the large raceway (Fig. 13). Water temperature ranged from a low of 19.2°C to a high of 29.5°C. Water lost during filtration and losses due to accidents and evaporation were replaced. Salinity ranged from 19 ppt to 27 ppt, and pH ranged from an initial high of 8.7 to a low of 7.5. Total alkalinity increased during this experiment. Ammonia concentrations ranged from 5.0 to 165.0 ug atoms NH₃-N/liter; nitrite from 0.3 to 162.3 ug atoms NO₂-N/liter; nitrate from 12.9 to 672.0 ug atoms NO₃-N/liter and inorganic phosphate phosphorus from 20.0 to 700.0 ug atoms PO₄-P/liter.

During the 3-month period of this experiment seawater from the raceway was analyzed as it entered and as it left the operating bio-disc filter. An average decrease in ammonia content of 53.4% a decrease in nitrite of 24.8% and a decrease in the inorganic phosphate phosphorus of 6.3% occurred during passage through the filter. The nitrate content was not changed significantly.

During the middle of January 1974, we ran out of our maintenance diet, and converted to another diet that broke down readily. Once again the particulate load increased and the shrimp became very active, occasionally jumping out of the raceway. Although the water was flushed through the filter bags, we were unable to reduce the particulate load significantly at the high feeding levels; therefore, we decided to terminate this experiment in February 1974. Water from the raceway was drained until only 7.5 cm remained. It was observed that a sludge, composed of uneaten food, feces and particulate waste, covered the entire bottom. With most of the water drained, the sludge concentrated, and the airlifts inoperative, oxygen levels dropped and in a matter of minutes the entire population died. An estimated 80% of this population survived from the October stocking. The shrimp averaged 88.3 mm in length and 5.6 g in weight (Fig. 12).

Rearing Experiment A

Analysis of the data from the previous experiments revealed two major problems. In the system with sunlight considerable growth of attached algae occurred. Food and waste were trapped by the algae and fouled. Therefore, we shaded the raceway with a strip of Griffolin, white and black polyethylene, 6 x 30 m, positioned on top of the bubble. The exposed areas of clear plastic on either side of the polyethylene were painted with a white latex paint. This shading eliminated the algal problem.

The second problem was that the airlift pumps which were positioned away from the center wall obstructed flow and produced numerous eddies which created zones of settling and fouling. Therefore, to utilize the scouring action of the water mass, while still maintaining turnover and circulation, the airlift pumps were positioned in the center of the raceways. Pumps were directed at a 45° angle from the center wall in one raceway and 45° and 90° in the other (Fig. 1-B, C). Pumping rates of 100-120 liters/min were maintained with an air flow of 2.8 liters/min for each airlift pump. Flow direction was clockwise, maintained at 9.2 cm/sec in each raceway. The circulation pattern created by the airlift pumps insured that the bottom was constantly being scoured and particulate matter was suspended in the water column except for the end zones where it settled.

On March 8, 1974, *Penaeus aztecus* were spawned in our hatchery. Twelve days later, a portion of the postlarval shrimp were transferred to the small hatchery raceway, held for 41 days and then moved to the large aquacell raceway. Initial stocking was 12,500 in the large raceway. Results of this rearing experiment are presented in Figure 14.

Initially, this raceway was filtered with only the pressurized filter at a flow rate of 100 liters/min. On June 4, 32 days after the experiment began, the Pielkenroad trickling filter was put into operation at a flow rate of 40 liters/min. Eight days later the plate separator was connected and operated at a rate of 28 liters/min. Due to evaporation and loss of water when back flushing, we had to add an average of 2,000 liters of water every 5 days to the raceway.

Water chemistry analysis was initiated March 21 in the small hatchery raceway (Fig. 15) and in the large raceway April 30 (Fig. 16). In the hatchery raceway salinity ranged from 18 ppt to 24 ppt. Changes in salinity can be accounted for by addition of sea water of different salinity to compensate for evaporation. The temperature ranged between 23.4°C and 28.5°C and the pH ranged from 8.4 to 7.4. Ammonia levels ranged from 26.0 to 66.0 ug atoms NH₃-N/liter; nitrite from 9.5 to 335.1 ug atoms NO₂-N/liter; nitrate from 18.6 to 44.8 ug atoms NO₃-N/liter and inorganic phosphate phosphorus from 1.5 to 85.0 ug atoms PO₄-P/liter. Fluctuations in levels of inorganic nutrients were probably a result of changing phytoplankton abundance and composition. Typically, the abundance and composition of the flora was not stable.

Chemical analyses in the large raceway (Fig. 16) included observations of water quality before and after passage through the Pielkenroad trickling filter. Average decreases of 34.8% for ammonia, 43.2% for nitrite and 1.5% for nitrate were observed as water passed through the filter at a rate of 40 liters/min. The overall effects of the filter on the inorganic phosphate phosphorus were not apparent. In some instances there were increases in the inorganic phosphate phosphorus in the filter (Fig. 16). It has been suggested that flocculation and settling of organically bound phosphorus in the filtration unit and its subsequent decomposition may cause an increase in phosphorus (Anonymous, 1971). The pH of the effluent was consistently 0.2 units higher than the influent. The bars with hatched marks (Fig. 16) indicate the levels of the various parameters measured in water having

passed through a second Pielkenroad filter.

In the large raceway there was a noticeable downward trend in the pH from an initial high of 8.4 to a low of 6.8. Fluctuation in levels of dissolved inorganic nutrients was noted from the onset of the experiment. Ammonia concentrations in the raceway ranged from 20.0 to 107.0 ug atoms NH₃-N/liter; nitrite from 2.0 to 186.5 ug atoms NO₂-N/liter; nitrates 25.2 to 454.3 ug atoms NO₃-N/liter and inorganic phosphate phosphorus from 1.5 to 680.0 ug atoms PO₄-P/liter. Following an accidental loss of water on August 16, 8,000 liters of new water were added to the raceway. An immediate reduction in inorganic phosphate levels was noted; however, effects on other parameters were not identified.

The system functioned smoothly until we began feeding the extruded diet. During the first part of August, a chitinoclastic bacterial infection was observed. It was also noted that the shrimp were jumping and that the water had a heavy particulate load. We were not feeding over 3.3 kg of food a day. The pressurized filter clogged readily, which in turn reduced the efficiency of the trickling filter. To reduce the particulate load, we lowered a sump pump, operating at 80 liters/min, directly into the raceway with the discharge flowing through a series of 25-micron filter bags. This procedure was followed for over a week. On August 23, we ran out of the experimental diet and switched to a new experimental shrimp feed. Unfortunately, this diet was poorly bound and the particulate load once again increased. The shrimp were under stress and very active; therefore, on September 11, we terminated this experiment.

The water was drained until only 7.5 cm remained in the raceway and it was noted that no debris of any kind was present in the system. Although the shrimp were not 202 days old (egg to juvenile) and growth had not been particularly good (average length 85.5 mm and average weight 5.0 g), 95.3% of the population had survived from post-larvae (Fig. 14). Examination of these shrimp revealed no infection of the chitinoclastic bacteria.

Rearing Experiment D

Postlarval brown shrimp reared in the hatchery raceway during Experiment C were also used in this experiment (Fig. 17). Two days after stocking this aquacell raceway with 12,556 (71/m²) juvenile shrimp, the pressurized filter was attached and operated at a pumping rate of 100 liters/min. Twenty-three days later, the Pielkenroad trickling filter was put into operation at a flow rate of 40 liters/min. The pressurized and trickling filters were operated at one end of the raceway, while a rectangular settling tank was tested at the opposite end. This tank was drained and flushed weekly, whereas the pressurized filter was backwashed twice daily.

In late May the shrimp were jumping and the particulate load was heavy; therefore, we submerged the sump pump into the raceway and flushed the water through a 25-micron filter bag for 4 days (6 hours a day) at a pumping rate of 80 liters/min. After 7 days operation, the rectangular settling tank was replaced with a round settling tank and

protein skimmer. Although the system was operating satisfactorily, we removed the pressurized filter and tested a liquid cyclone designed to remove particulate matter. The unit was tested at low pumping pressures and therefore continually clogged. Because of the build-up of particulate debris, we replaced the cyclone with the pressurized filter.

About 15% of the population appeared to be infected with a chitinoclastic bacteria on July 31. On August 3, as a result of a power failure, circulation stopped and the shrimp became very active. Once the airlift pumps began operating, the shrimp settled down. By August 15, we were feeding over 3.7 kg of food daily and the particulate load was heavy. A sump pump was lowered into the raceway, and water was flushed through a 25-micron bag for 7 days, 6 hours a day at 80 liters/min. Chemical determinations during this experiment are presented in Figure 18. The ammonia concentration of the raceway seawater ranged from 26.0 to 74.0 ug atoms $\text{NH}_3\text{-N/liter}$; nitrite from 2.1 to 135.8 ug atoms $\text{NO}_2\text{-N/liter}$; nitrate from 10.0 to 421.0 ug atoms $\text{NO}_3\text{-N/liter}$; and inorganic phosphate phosphorus from 15.0 to 745.0 ug atoms $\text{PO}_4\text{-P/liter}$. As in previous experiments there was an initial peak in ammonia concentrations, followed by peaks in nitrite and nitrate concentrations. Fluctuations in ammonia and nitrite concentrations were observed throughout the experiment, whereas there was an increase in the nitrate and inorganic phosphate phosphorus concentrations. The pH exhibited an erratic but progressive decline from 8.4 to 6.9.

In water passing through the Pielkenroad trickling filter there was an average decrease in ammonia and nitrite levels of 30.0% and 37.0%, respectively, at flow rates of 40 liters/min; however, on many occasions there were increases in nitrate and phosphate-phosphorus levels.

We terminated this experiment on September 4. The shrimp averaged 80.0 mm and 4.0 g after 181 days (egg to juvenile). Of the juvenile shrimp stocked in May, 99% were recovered and none of the shrimp showed signs of infection by the chitinoclastic bacteria.

DISCUSSION

Although these experiments were of a preliminary nature, it was demonstrated that juvenile penaeids could be reared at high densities in closed systems. Both the Pielkenroad trickling filter and the bio-disc filter were effective means of removing dissolved wastes from the seawater systems. The Pielkenroad plate separator operated efficiently in removing particulate wastes from the systems.

Shrimp in the aquacell raceways tolerated wide ranges of ammonia (20.0-107.0 ug atoms $\text{NH}_3\text{-N/liter}$), nitrites (2.0-186.5 ug atoms $\text{NO}_2\text{-N/liter}$), nitrates (10.0-454.3 ug atoms $\text{NO}_3\text{-N/liter}$), and inorganic phosphate phosphorus (1.5-745.0 ug atoms $\text{PO}_4\text{-P/liter}$) without apparent adverse effects. On several occasions when water quality was judged poor, and particularly when concentrations of nitrites were high, shrimp exhibited abnormal behavior indicative of stress.

Ammonia and nitrate concentrations in the raceway systems fluctuated, whereas nitrates and inorganic phosphate phosphorus tended to accrue. The pH of the raceway systems declined throughout the duration of each experiment; however, pH never dropped below 6.8.

Rearing postlarval or juvenile shrimp at high densities in systems such as this is a means of providing a supply of shrimp for stocking ponds early in the season when cold weather is a limiting factor. The technique is also useful if stocking ponds or raceways with juvenile shrimp is desirable to utilize space more efficiently.

We believe the principles and techniques demonstrated during these experiments have useful application in the rearing of larger penaeid shrimp and many other marine animals in closed systems.

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